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INVESTIGATION OF TIES AND

ADAPTIVE ANTENNA TECHNOLOGY COMPATABILITY

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ABSTRACT

TIES (Tactical Information Exchange System) is being developed by the Navy to provide a new architecture for airborne CNI (communication, navigation and identification). An adaptive array (AA) can provide jam resistance to CNI receivers by spatially nulling interferences. The results of an investigation of the compatibility of AA processing within the TIES are presented. Candidate implementation schemes are examined for the TIES-AA.

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1.0 INTRODUCTION

The TIES (Tactical Information Exchange System) avoids the need for redundancy of electronic subsystems that now exists among the set of CNI receivers on many aircraft. A broadband signal distribution system for TIES is installed in each aircraft to convert RF signals from antennas at HF (2-30 MHz), VHF, UHF (225-400 MHz) and LX band (960-1215 MHz) to IF and to convey them to a central processor. Common module central IF filters, amplifiers, demodulators, etc. with digitally programmable bandwidths, gains, etc. service signals received from all bands.

An adaptively controlled N element array can protect a receiver by forming an RF beam with nulls toward as many as N-1 jammers. Using the TIES and an IF beamformer, the adaptive array (AA) processor can form N-1 nulls in any frequency band and thereby protect any airborne receiver for which an array of N antennas is provided.

This report presents candidate implementations (in block diagram form) of a TIES-AA for the case where a coaxial cable and FDM (frequency division multiplexing) provide the wideband signal distribution system.

1.1 A Brief Description of TIES

The TIES accepts RF signals received by several antennas covering various frequency bands. The TIES consists of three basic subsystems:

- (1) The frequency conversion subsystem
- (2) The signal distribution subsystem
- (3) The signal conversion subsystem.

We briefly describe below the functions of these three subsystems with emphasis upon the receiving mode since the adaptive array design has only secondary impact upon the transmit mode. A more complete description may be found in (1).

1.1.1 Frequency Conversion Subsystem

The frequency conversion units establish the receiver noise figure, provide gain, selectivity, synthesize the local oscillator (LO) and provide AGC. A 70 MHz standardized IF is used throughout TIES. These IF signals are upconverted to UHF or SHF and are coupled to a wide band FDM signal distribution system. In transmit the system operates in reverse fashion. Many system parameters, such as channel bandwidth or AGC, are controlled by the signal distribution system.

1.1.2 Signal Distribution Subsystem

A control signal distribution system manages the traffic of control signals to each remote input and output and provides translation between digital control words and control action. The remote modules translate addresses and control signals to control points.

The wideband distribution subsystem consists of a series of coupling units and wideband FDM signal cables. Coupling units are frequency converter/tunable filter combinations which shift 70 MHz IF signals onto or down from the wideband cable. Any received signal can be programmed to any output FDM cable interface.

A data distribution system conveys digital information among the signal conversion subsystem, the input/output devices, built in test equipment and external test interfaces.

1.1.3 Signal Conversion System

Wideband data processors operate upon JTIDS, TACAN and IFF waveforms obtained via the FDM cable. Bit formatting, error detection and correction coding/decoding (CODEC), modulation/demodulation (MODEM) and I/O interface functions are also performed.

Narrowband signal conversion resources are programmable units which perform MODEM and CODEC functions on Link 11, Link 4, AM, FM, SSB and TTY signals obtained via the FDM cable.

1.1.4 TIES Functional Diagram

The TIES design concept is illustrated in Figures 1-1 and 1-2 with the three subsystems and their interfaces identified. The TIES FDM bus receive configuration is illustrated in Figure 1-3.

1.2 Adaptive Arrays for Airborne Receivers

In a typical airborne system each receiver operates with its own antenna. Thus when it came to providing ECCM to protect an airborne receiver, it naturally followed that one should provide a separate antenna array and adaptive control unit for each receiver. Adaptive nulling arrays have received much attention during the past six years and the literature contains numerous theoretical and experimental results(2,3,4,5). Here we briefly summarize the structure and subsystems of an adaptive array (AA) so that this report can stand on its own.

Figure 1-4 illustrates an N element array employing the Least Mean Squares (LMS) adaptive control algorithm. The processing of each receiving antenna's output is the same so only the n-th channel is shown. The AA consists of four subsystems:

- (1) The array of antennas
- (2) The beamformer subsystem
- (3) The adaptive control subsystem
- (4) The wavefront sampling subsystem

The antennas are the transducers between the incident waves in free space and the RF transmission lines leading to the receiver. In an N element array the spatial pattern can

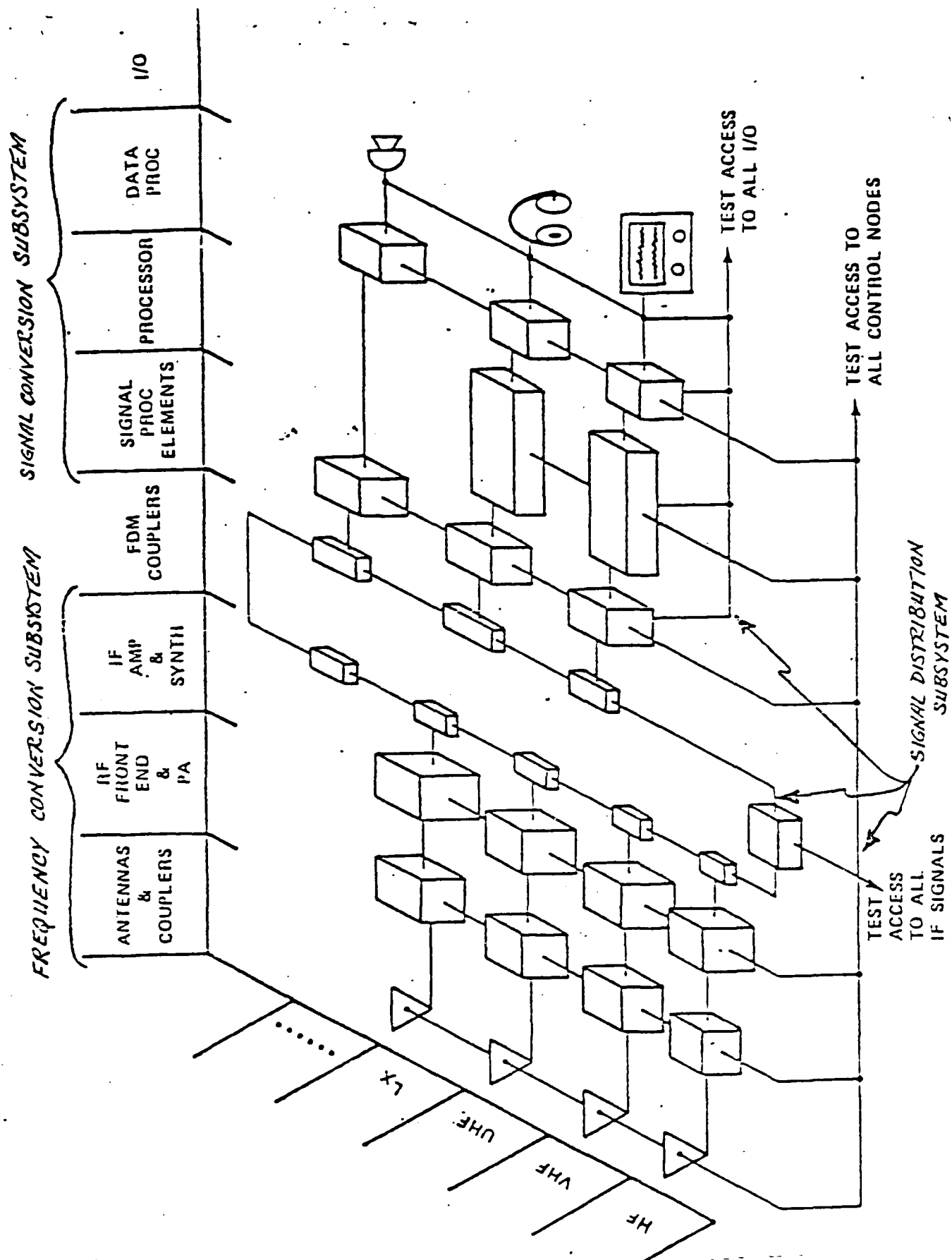


FIGURE 1-1 WTRC SYSTEM ARCHITECTURE

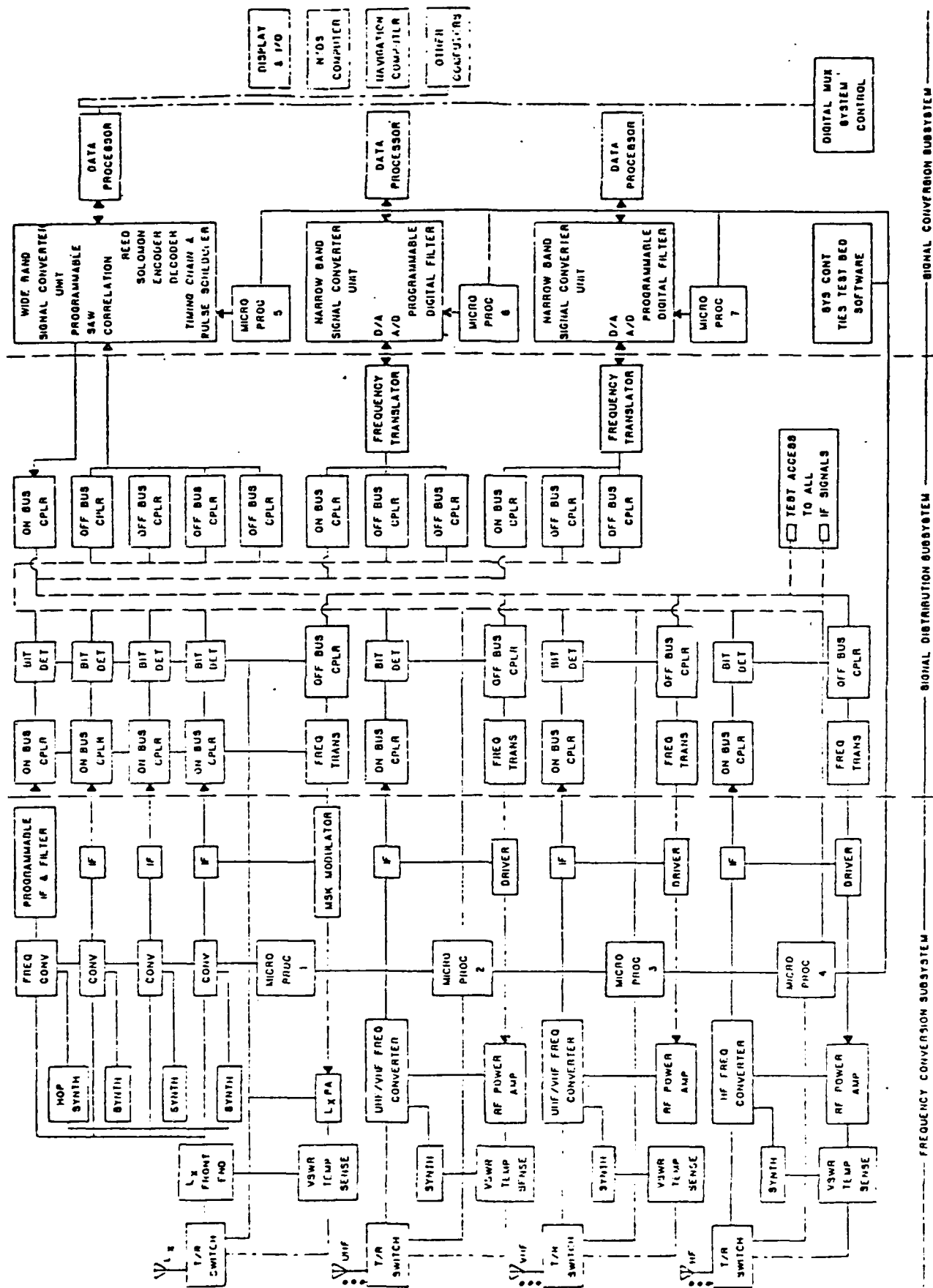


Figure 1-2 TIES BLOCK DIAGRAM

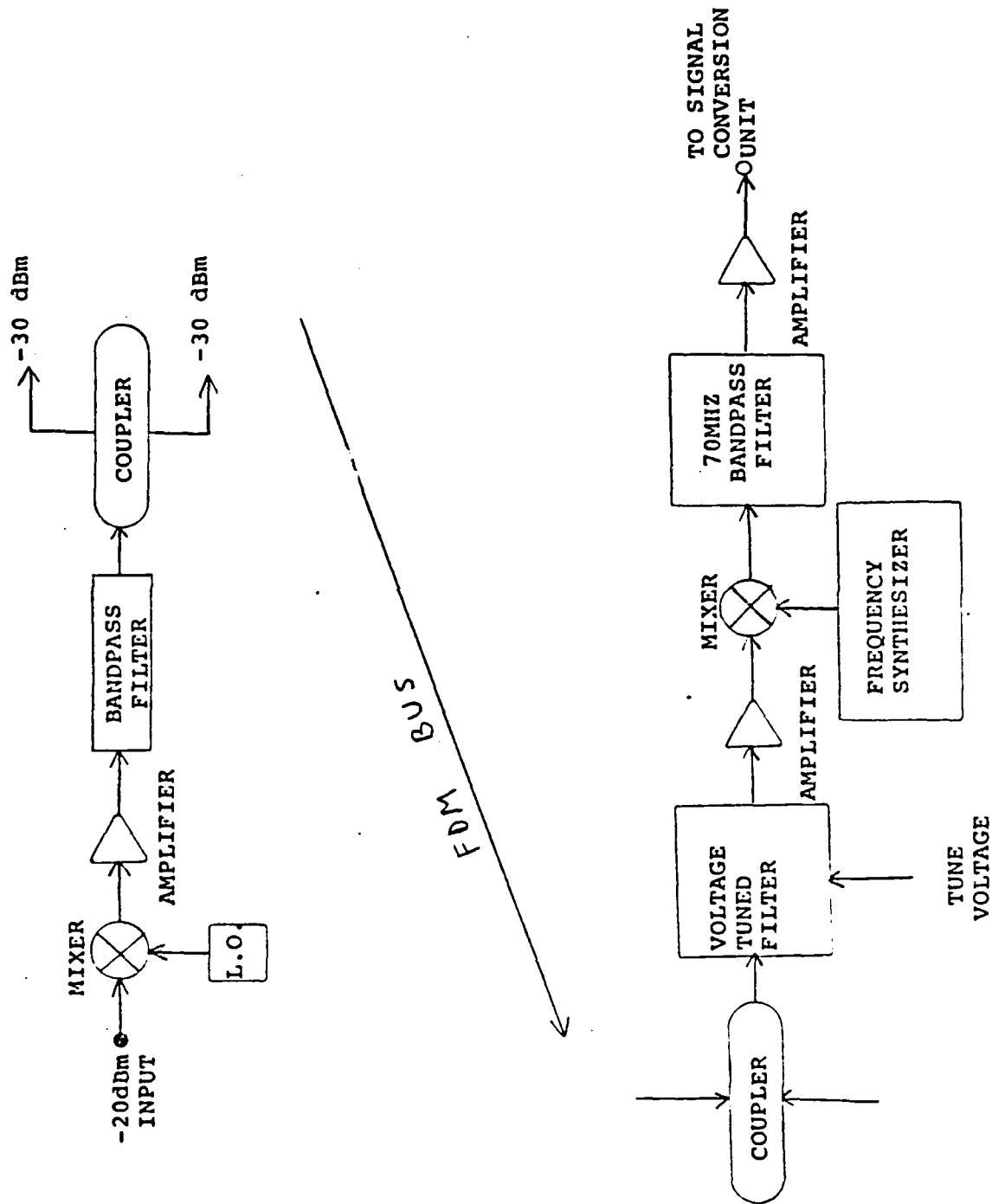


Figure 1-3 TIES FDM RECEIVE BUS INTERFACE

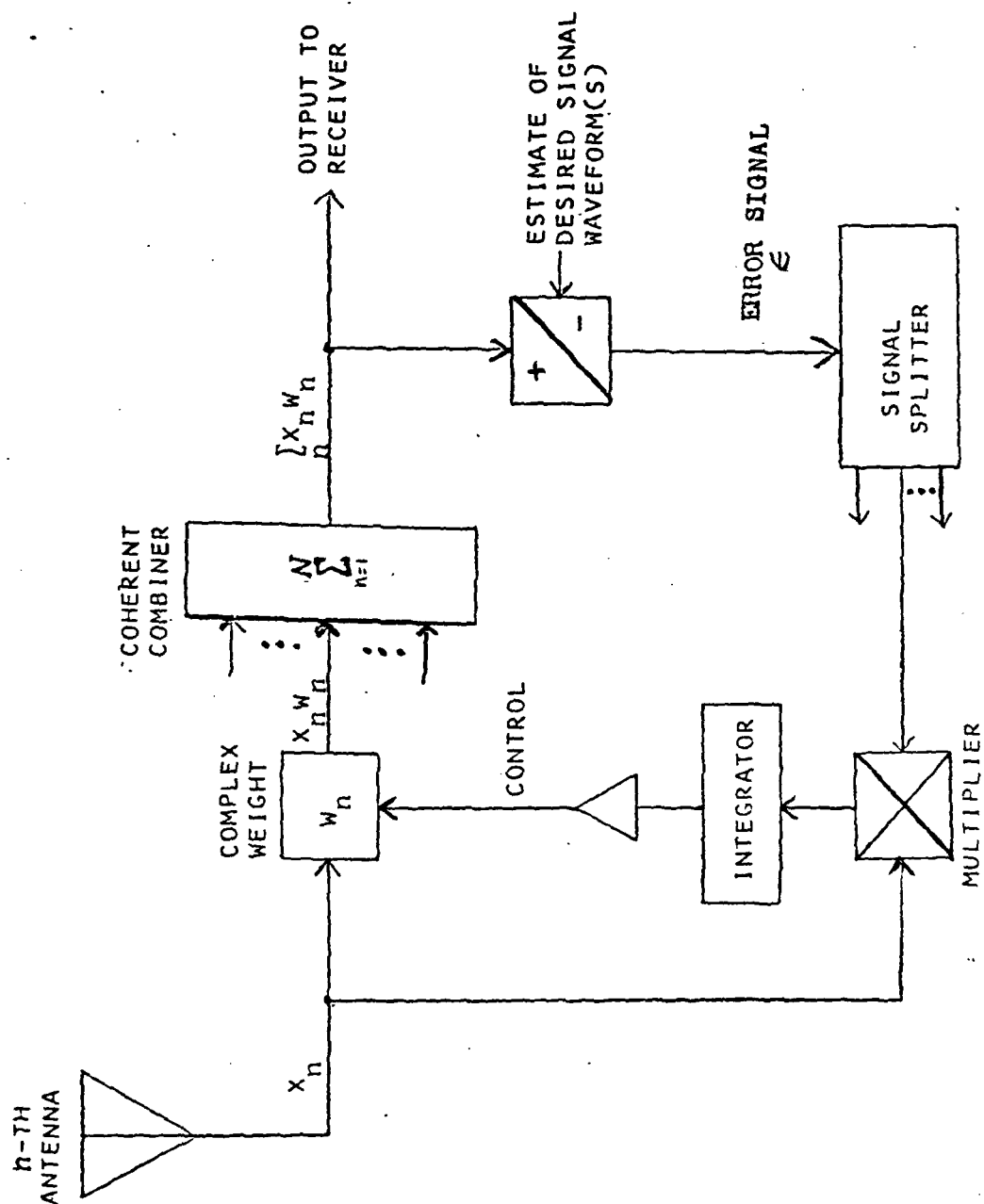


Figure 1-4 ADAPTIVE NULLING ARRAY EMPLOYING THE
LEAST MEAN SQUARES (LMS) ALGORITHM

be independently specified in at most $N-1$ distinct directions. Thus a four element array is required to null three independent jammers.

The beamformer consists of N complex weights (phase and amplitude adjustment of the N received waveforms) and an N -way coherent summer. The power pattern (antenna spatial response) is established at the beamformer output. Beamformers can be implemented at RF, IF or baseband. Beamformers can be distributed (complex weights located with antennas), or compact (transmission lines bring the antenna signals to a central processor).

The adaptive control unit adjusts the beam pattern by varying the N complex weight values in the beamformer in response to the electromagnetic environment incident upon the array and upon a algorithm (prescribed course of action based upon a goodness criteria such as maximum signal-to-noise ratio).

The wavefront sampling system makes the N received signals X_1, \dots, X_N available to the adaptive control unit. For the LMS

algorithm (a steepest descent approach), the time derivative of the n -th weight is proportional to the correlation of X_n and the error signal ϵ . As seen in Figure 1-4 ϵ is the difference between the beamformer output and an estimate of the desired signal waveform. As the error signal is driven toward zero by the N feedback control loops the jammers are nulled in the beamformer output and the desired signal is forced to the level of the estimated desired signal (reference waveform level).

The beamformer output drives only one receiver and the N -loop adaptive control system can only process the outputs from one array of antennas in a conventional system. This situation is illustrated in Figure 1-5 where much replication of similar components exists.

1.3 Adaptive Array for Aircraft with TIES

The AA illustrated in Figure 1-4 has much in common with the TIES illustrated in Figure 1-1, namely, they each consist of many nearly identical channels and subsystems whose functions can be carried out at RF or IF. It seems almost a natural marriage to use the TIES frequency conversion and signal distribution subsystems to bring the signals from an antenna array at HF (or VHF or UHF or Lx band), to a central array beamformer and central adaptive control system that operates at a common IF (Figure 1-5).

One advantage of TIES-AA is that a single IF AA processor can serve the several frequency bands that are used and thus offer anti-jam (AJ) protection to a wide variety of on-board receivers. A second advantage is that many of the array functions can be implemented at IF using common modules already developed for TIES.

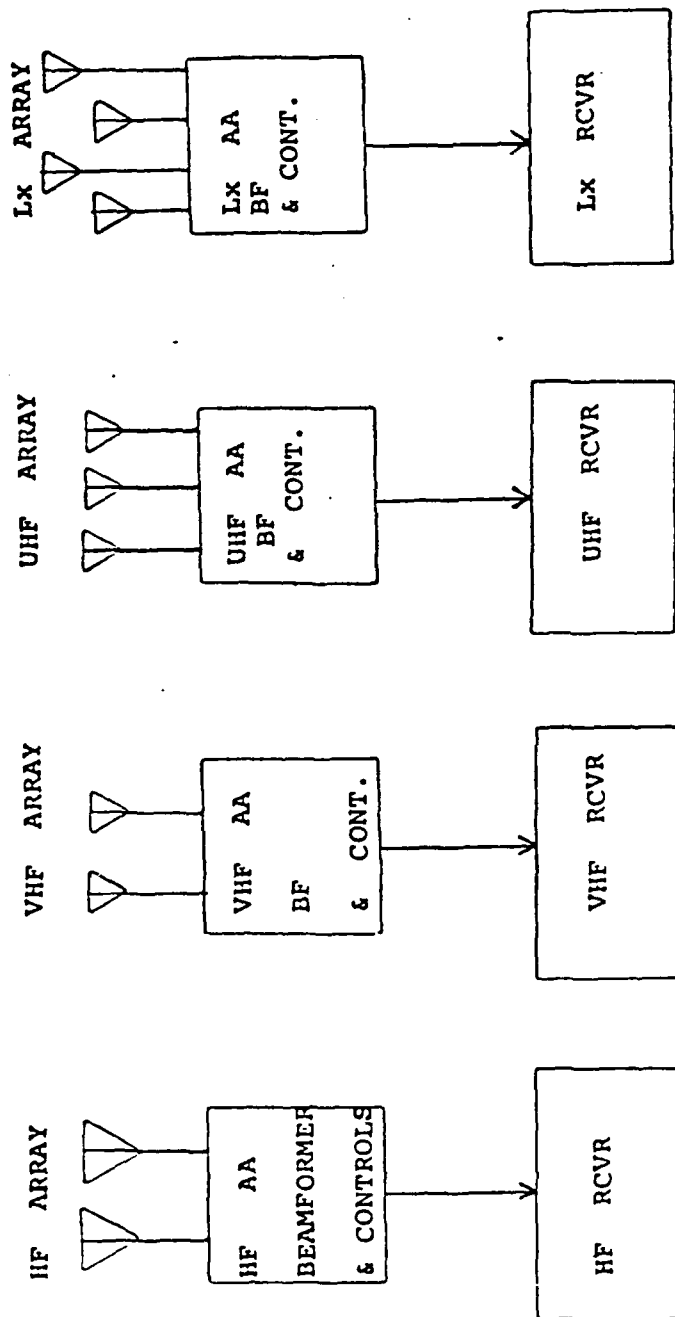


Figure 1-5 CONVENTIONAL AIRFRAME SUITE WITH ONE ADAPTIVE ARRAY PER RECEIVER

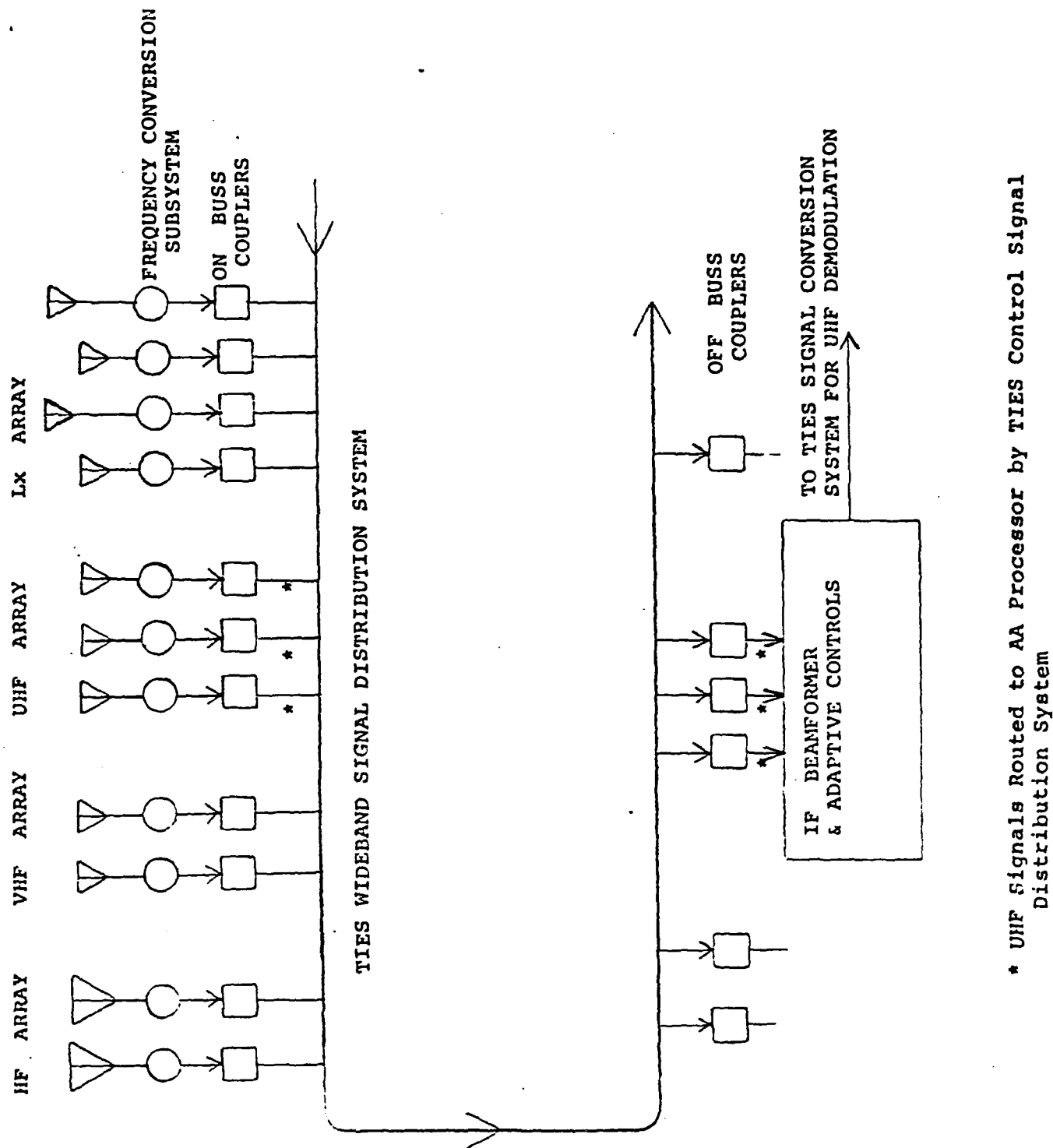


Figure 1-6 CONCEPT OF TIES AND IF - AA

* UHF Signals Routed to AA Processor by TIES Control Signal Distribution System

Thirdly, resource sharing is possible. When the VHF band is only threatened by a few jammers, IF LMS control loops can be reassigned to protect a severely threatened Lx band receiver.

The remainder of this report examines hardware and system considerations concerning the compatibility of TIES and a multiband IF AA processor. Several novel AA concepts are presented which indicate hardware cost savings by further multiplexing AA functions to take advantage of the FDM of the antenna outputs by the TIES.

2.0 ADAPTIVE ARRAY HARDWARE CONSIDERATIONS

2.1 The Adaptive Array Beamformer

The beamformer of an adaptive array is diagrammed in Figure 2-1. It forms the weighted sum of the waveforms from each antenna element, where the weighting is in general complex (both amplitude and phase). In some cases, one of the weights is held at a fixed value, and the others are then scaled to that value. It can be applied at RF or after frequency conversion to IF.

Adaptivity is obtained when the values of the adjustable complex weights are set as a function of the interference and signal scenario to optimize the array performance.

2.2 Implementation of the Complex Weight

The complex weight is most conveniently implemented by two real weights in phase quadrature, as shown in Figure 2-2. The input at RF or IF is split into two quadrature components (I and Q). A small portion of each of these components is coupled off for use by the adaptive control unit. The main portion of each of these components is adjusted in amplitude (with sign) by the I and Q balanced modulators, whose input control voltages are provided by the adaptive control unit. The modulator outputs are combined in phase to provide the complex weight output at the same frequency as its input.

The implementation of Figure 2-2 allows the complex weight to assume values in the complex plane denoted by the shaded region of Figure 2-3. The values A_I and A_Q correspond to the maximum scale factors that can be obtained from the I and Q balanced modulators. If the balanced modulators are passive, then both A_I and A_Q are less than unity.

2.2.1 Balanced Modulator Implementation

Two alternative implementations of the balanced modulator are shown in Figure 2-4. Figure 2-4A shows a balanced diode mixer implementation, which is passive. The DC control input controls the relative conduction of the four diodes in the bridge arrangement, thereby controlling the coupling factor of the high frequency input to the output. When the DC input is positive, diodes CR1 and CR3 conduct more than CR2 and CR4, so the input is coupled to the output without inversion. As the DC input is made more positive, the coupling becomes increasingly stronger. When the DC input is negative, similar behavior occurs with CR2 and CR4 conducting more than CR1 and CR3, providing input-

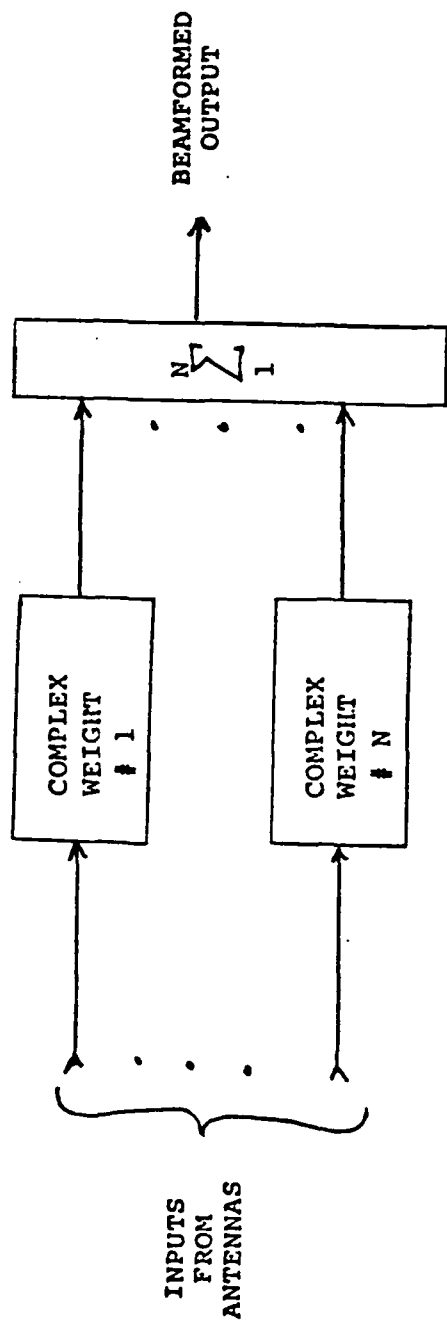


FIGURE 2-1 ADAPTIVE ARRAY BEAMFORMER

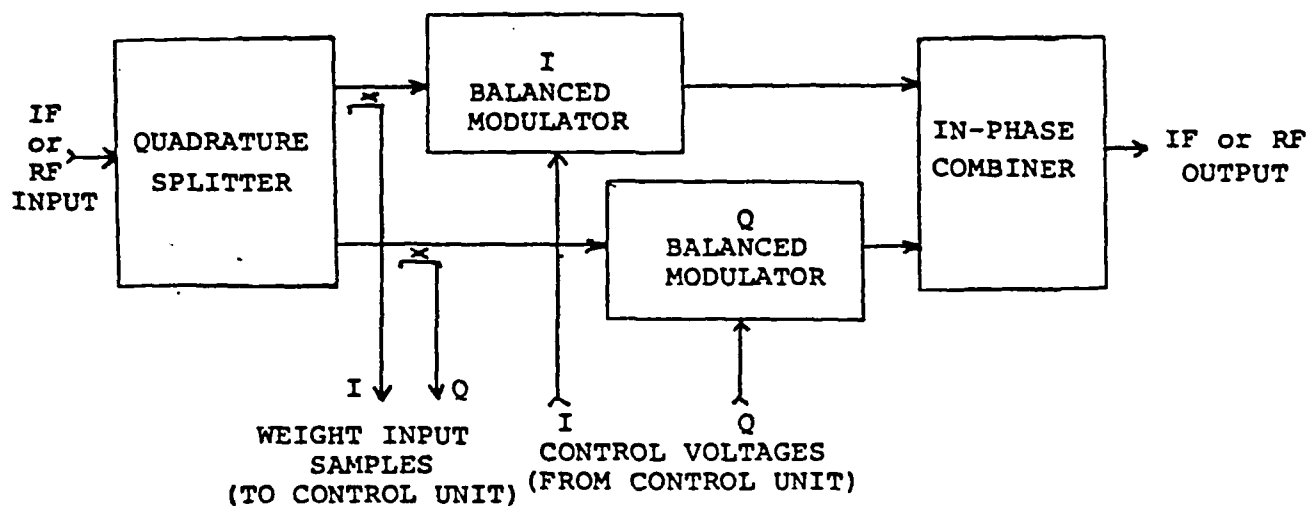


FIGURE 2-2 COMPLEX WEIGHT IMPLEMENTATION

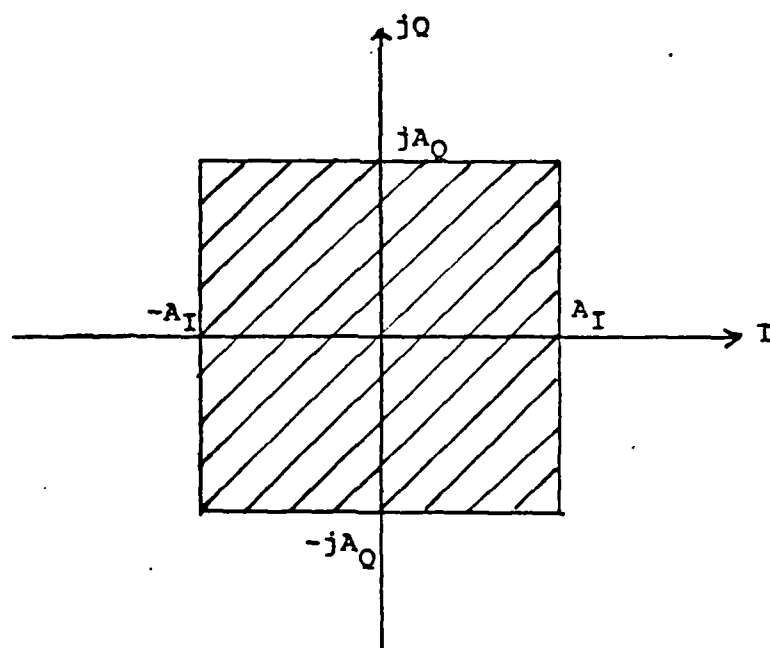


FIGURE 2-3 VALUES ATTAINABLE BY THE COMPLEX WEIGHT

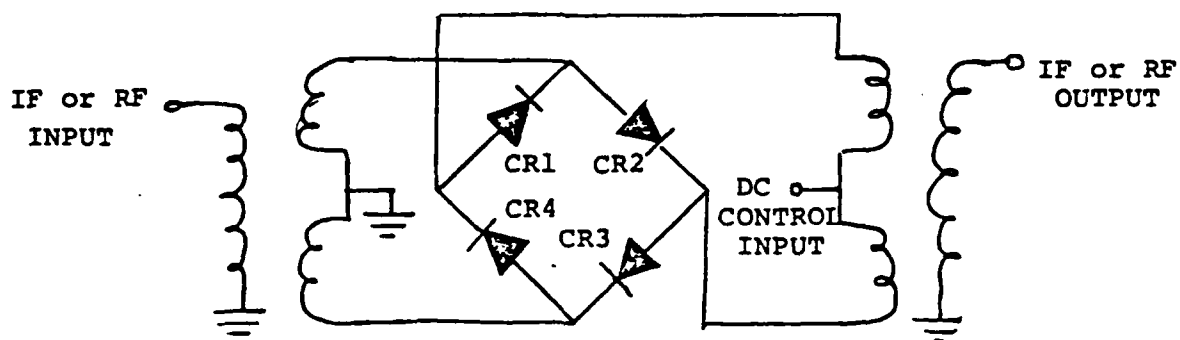


FIGURE 2-4A BALANCED DIODE MIXER IMPLEMENTATION

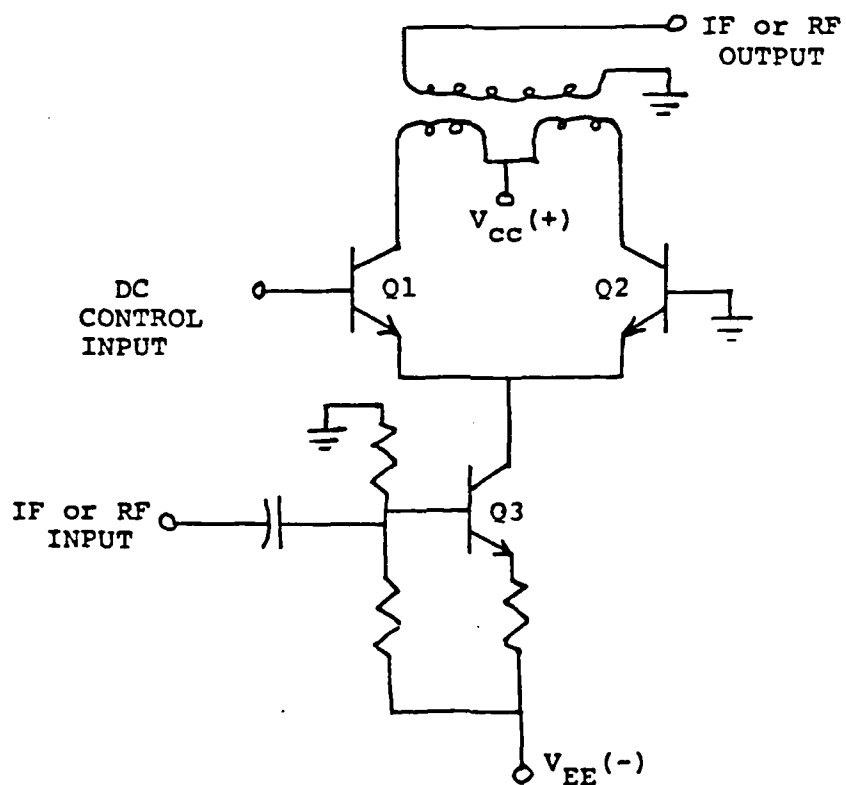


FIGURE 2-4B DIFFERENTIAL AMPLIFIER IMPLEMENTATION

FIGURE 2-4 BALANCED MODULATOR IMPLEMENTATIONS

output coupling with inversion. When the DC control input is 0V, the bridge is balanced and the input-output coupling is zero.

An active balanced modulator implementation is shown in Figure 2-4B, using a differential amplifier. Transistor Q3 acts as a current source, providing DC current plus an AC current generated by amplification of the IF or RF input. The current from Q3 is conducted through Q1 and Q2 in amounts relative to the DC control input. When the DC control input is positive, Q1 conducts more than Q2, and the output balun transformer provides a noninverted waveform whose amplitude is proportional to the DC control voltage. When the DC control voltage is negative, Q2 conducts more than Q1, and the output balun transformer provides an inverted waveform whose amplitude is proportional to the DC control voltage. When the DC control voltage is zero, both Q1 and Q2 conduct equal amounts of current, which sums to zero in the balun. Because this configuration is active, it can provide gain (A_I or A_Q is greater than 1).

Both configurations are available as integrated circuits. The differential amplifier configuration, when biased with a high DC current, can be made to provide a higher power output than the balanced mixer for the same relative level of distortion. Integrated balanced mixers are available for higher frequency operation than are integrated differential amplifiers. At the common IF of 70 MHz, either can be used.

2.3 LMS Control of the Adaptive Array

The implementation of an adaptive array with LMS (least mean square) control is diagrammed in Figure 2-5. Each of the complex weights is driven to minimize the correlation between the weight input and the feedback error signal. Since the weight inputs and controls are complex, the correlations are done for I and Q separately.

The error signal is split to feed the control unit for each complex weight. In the control unit the error signal is multiplied by the I input sample, and the result is integrated with negative gain to provide the I control voltage. The Q control voltage is obtained by an identical operation with the Q input sample.

The weight control unit comprises the 2-way error signal splitter, the I and Q multipliers, and the I and Q integrators. The complex weight and its control unit can be thought of as a control loop module. These modules are all identical.

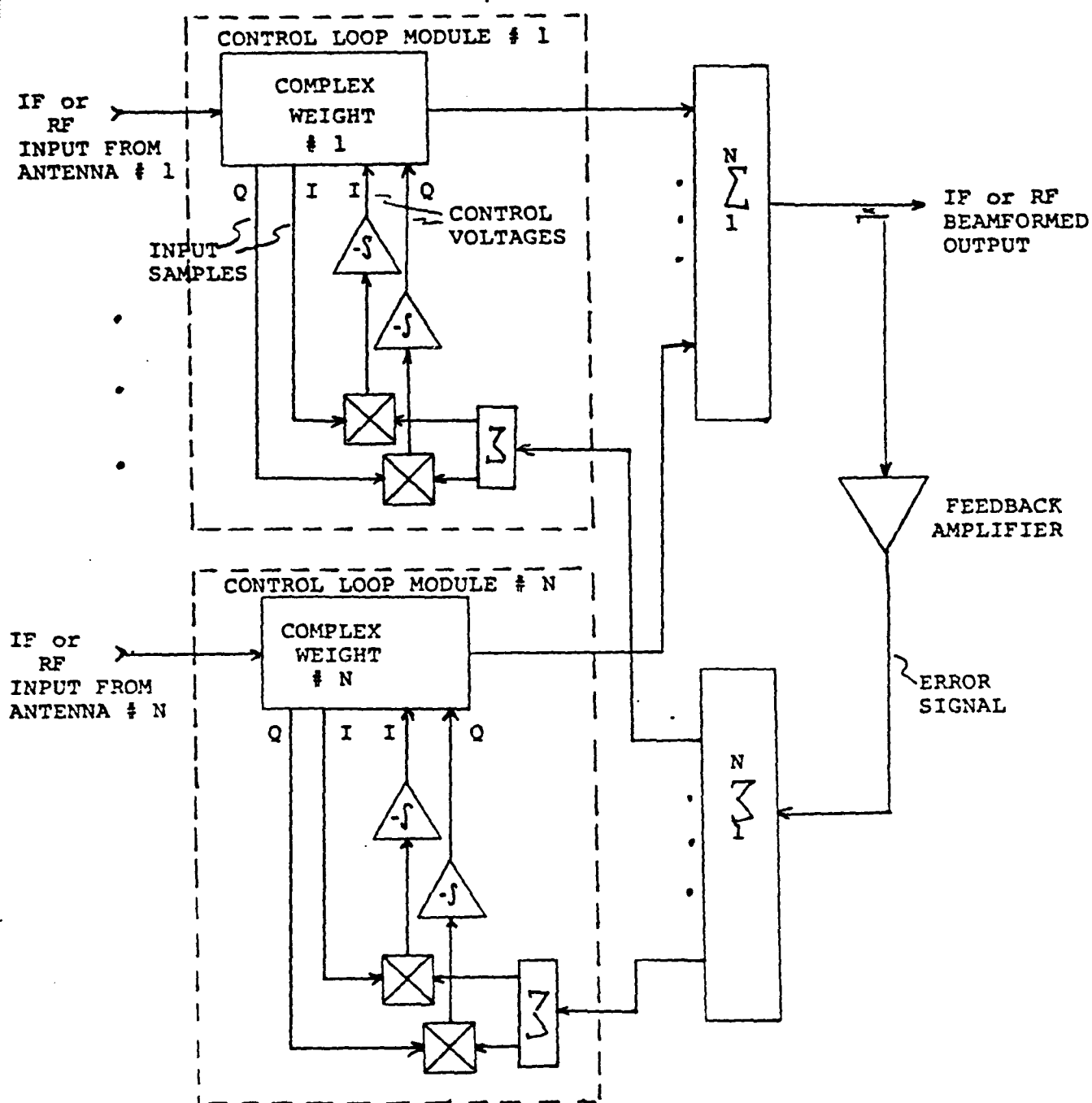


FIGURE 2-5 ADAPTIVE ARRAY WITH LMS CONTROL

2.3.1 Implementation of the Correlation Multiplier

The multipliers in the complex weight control unit can be implemented with the balanced mixer circuit of Figure 2-4A. To use this circuit as a multiplier, the two inputs are fed to the transformer-coupled ports. The output is taken from the DC - coupled port. A balanced mixer used in this manner is often referred to as a phase detector, since its output voltage is proportional to the cosine of the phase difference of the inputs.

2.4 Adaptive Array with a Time-Shared LMS Control Unit

As may be seen from Figure 2-5, the control units of each adaptive control loop are identical. Furthermore, all operations in the control unit are memoryless except for the integrator circuits. Because of these factors, some hardware economy can be achieved by time sharing a single control unit, with separate integrators for each output.

An adaptive array processor with a time-shared control unit is diagrammed in Figure 2-6.

It has two synchronized commutating switches, each with $2N$ positions: one switch to provide the I and Q weight input samples to the multiplier, and the second to distribute the multiplier output to each of the integrate and hold (I & H) circuits at the proper times. The I & H circuits are each provided with a control waveform to set them in "integrate" or "hold" at the proper times.

2.5 Multiple Adaptive Array Beamformers with a Single Time-Shared Control Unit

The economic value of a time-shared LMS control unit is greatest when it provides the control for several adaptive array beamformers. Such a system is diagrammed in Figure 2-7. Each beamformer consists of a set of complex weights and a combiner for their outputs, but their control voltages are all provided by a single time-shared control unit, as shown in the diagram of Figure 2-6.

Each beamformer has a separate output which provides the feedback error signal for the adaptive control. The error signals are all multiplexed onto the single error signal input of the time-shared control unit by an error signal commutator, allowing the use of a single feedback amplifier following the commutator. The error signal commutator must be synchronized with the commutators in the time-shared control unit.

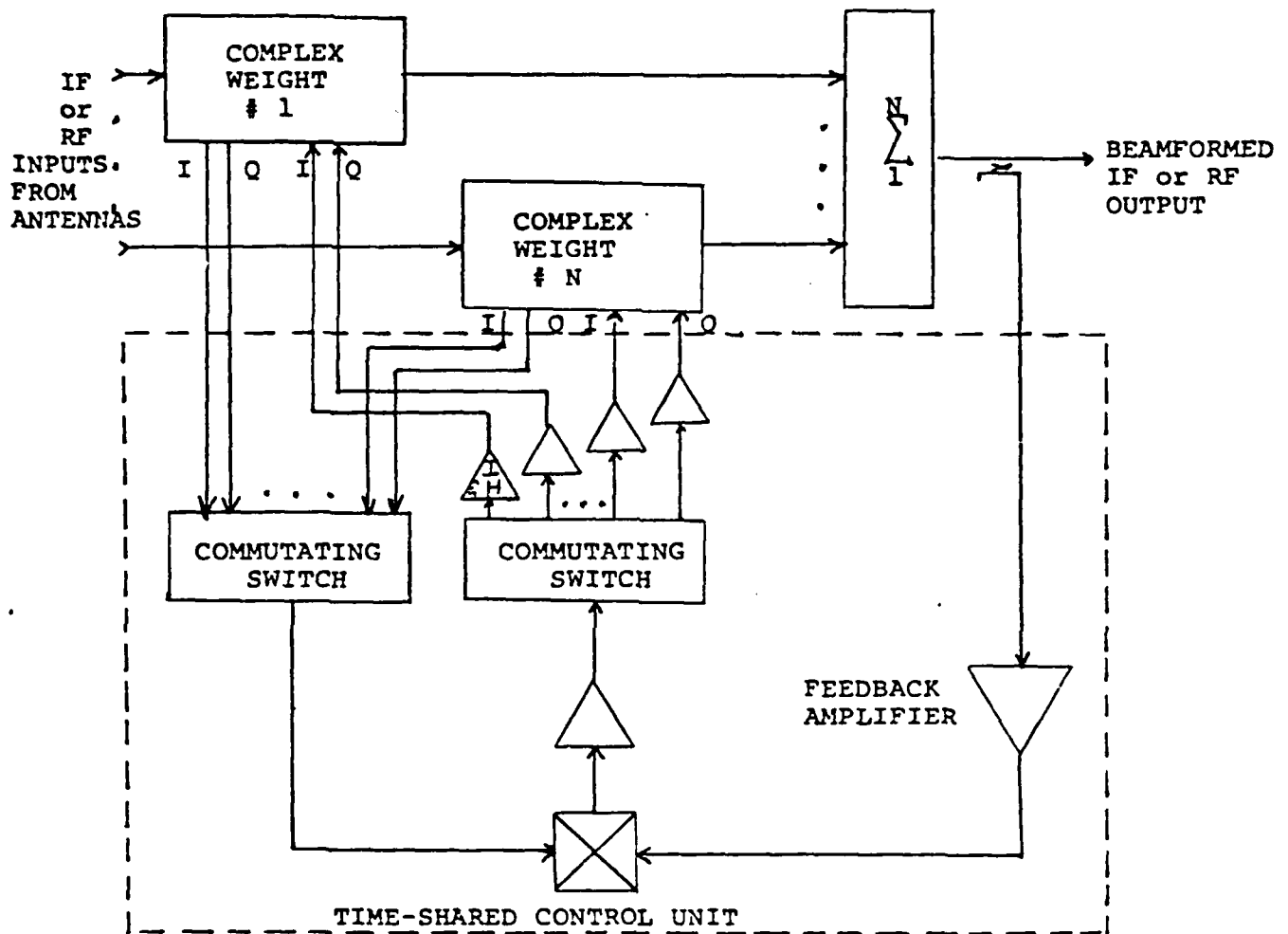


FIGURE 2-6 ADAPTIVE ARRAY PROCESSOR WITH
TIME-SHARED LMS CONTROL

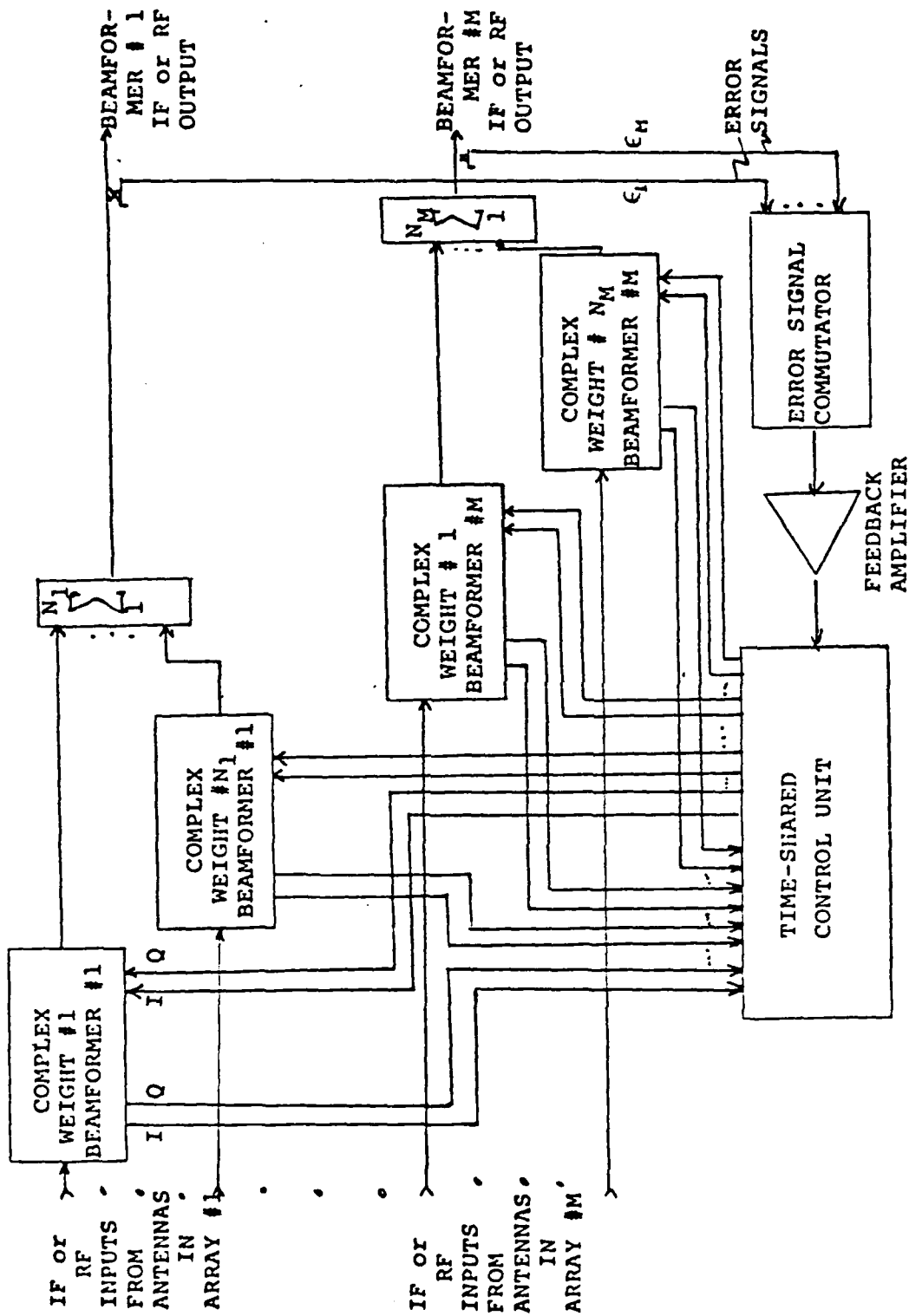


FIGURE 2-7 MULTIPLE ADAPTIVE ARRAY BEAMFORMERS WITH A SINGLE TIME-SHARED CONTROL UNIT

2.6 A Time-Shared Beamformer with Time-Shared Control

If the inputs to the complex weights were time-division multiplexed onto a single cable, then a single synchronized time-division multiplexed complex weight could replace the N weights of a conventional beamformer. This concept is illustrated in Figure 2-8. The antenna inputs to the complex weight are time-division multiplexed, as are its control inputs. One time-shared complex weight can then be used to apply the amplitude and phase scale factors sequentially to each of the inputs. The weight output then goes into a smoothing filter which combines the weighted time-division multiplexed inputs to form the antenna beam.

The design of the complex weight must allow it to change value quickly to keep up with the multiplexing rate. For 50 kHz wide channels, a complex waveform sample is required at least as often as every 20 microseconds. With several multiplexed antenna waveforms, the weight must be able to change value in a time period of the order of a microsecond. A complex weight using either of the balanced modulator implementations of Figure 2.4 is capable of meeting that requirement.

2.7 A Frequency-Multiplexed Beamformer with Frequency-Multiplexed Control

A frequency-multiplexed adaptive array processing system that is analagous to the time-multiplexed system discussed above is diagrammed in Figure 2-9. It shows the antenna inputs being frequency-multiplexed onto a common cable using a bank of local oscillators (L.O.'s), and then applied to a frequency-shared complex weight. The control input to the complex weight is also frequency multiplexed with the same frequency spacing, but shifted by some offset frequency. The complex weight output is then frequency shifted to appear at the offset frequency with all antenna signals weighted in amplitude and phase, restored to a common frequency, and combined. Extraneous frequency products are rejected by the bandpass filter.

The frequency-multiplexed control signals are obtained by multiplying the feedback error signal obtained from the array processor output by the frequency-multiplexed weight input. These components are then separated by a bank of narrowband filters implemented by converting each to DC, where they are integrated (or bandpass filtered), and then restoring them to their original frequency. The frequency conversion to DC and the frequency restoration must be done with I and Q components as shown so that all amplitude and phase

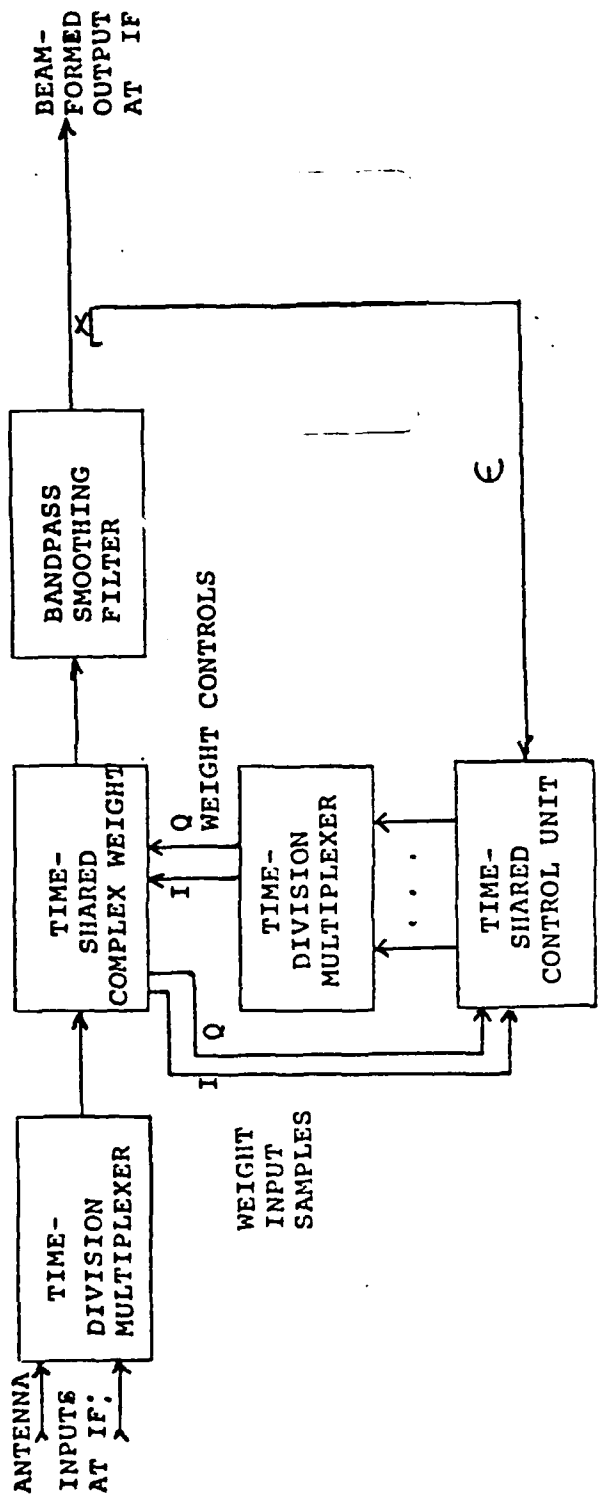


FIGURE 2-8 TIME-SHARED ADAPTIVE ARRAY BEAMFORMER WITH TIME-SHARED CONTROL

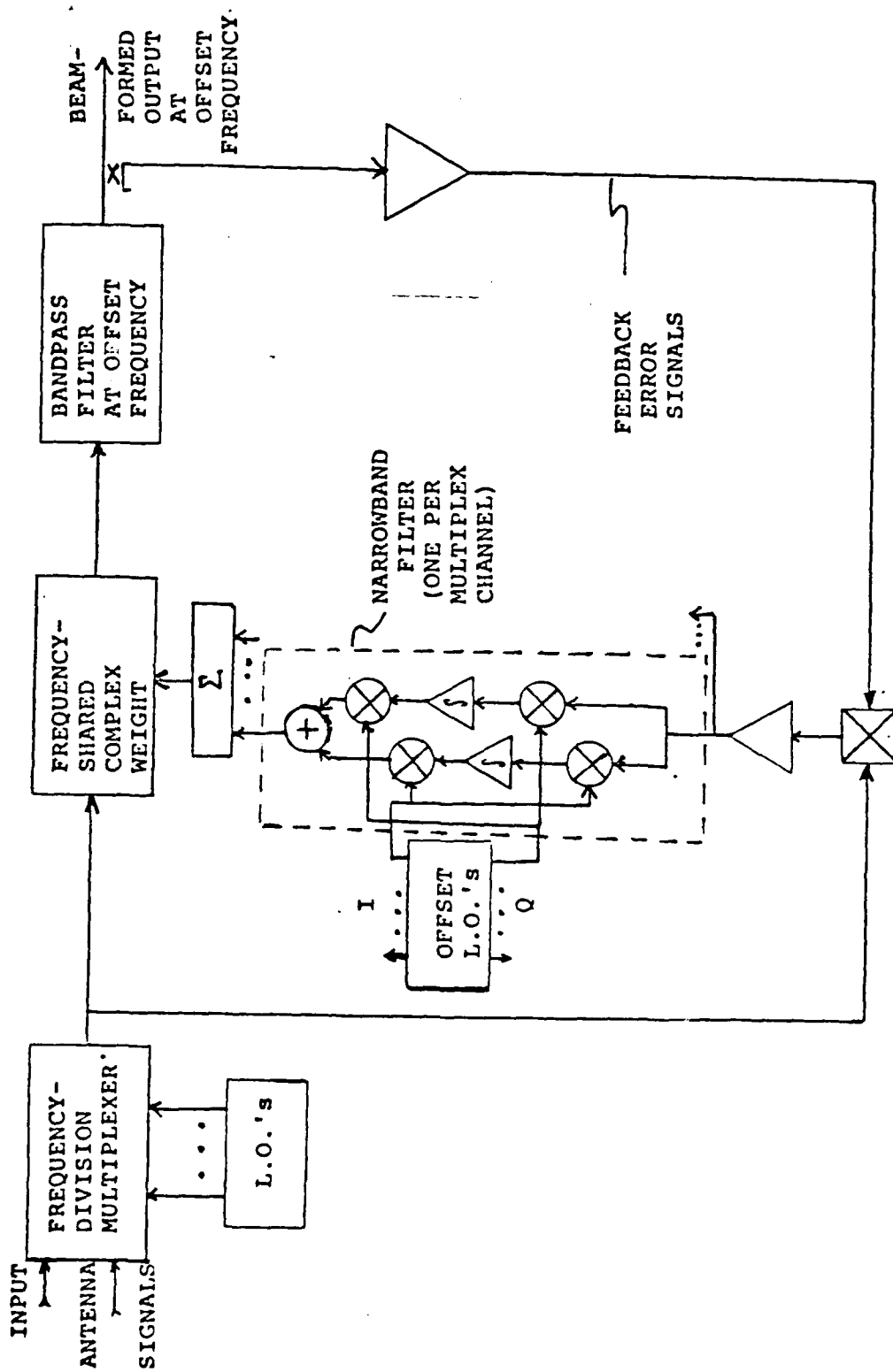


FIGURE 2-9 FREQUENCY-MULTIPLIED ADAPTIVE ARRAY BEAMFORMER
WITH FREQUENCY-MULTIPLIED CONTROL

information in the lowpass filter bandwidth is maintained. The L.O. for each narrowband filter is obtained by applying the offset frequency to the corresponding L.O. in the multiplexer.

The narrowband filter outputs are all combined to provide the multiplexed control input to the complex weight.

A complex weight operated in this fashion uses a narrowband AC control input for each multiplexing channel. The amplitude and phase of the control input are then transferred to the antenna signal in the complex weight, while at the same time shifting its frequency by an amount equal to the AC control frequency. An adaptive array processor using this means of control was built previously⁽⁴⁾ with very successful performance results.

The complex weight must be capable of responding to the highest multiplexed frequency at its control input. Both implementations of Figure 2-4 have good high frequency response. The diode bridge circuit of Figure 2-4A was used in (4) with its antenna input centered at 300 MHz and its control input at 64 MHz.

2.8 Recommendations for Future Work

Because the TIES system is frequency-multiplexed, it is recommended that development of a feasibility model of the frequency-multiplexed system of Section 2.6 be undertaken. The model should have four frequency-multiplexed inputs centered near 70 MHz. Three of them should be adaptively weighted and the fourth with a fixed weight, allowing nulling of up to three interferences. It is estimated that this feasibility model could be developed with approximately 1½ man-years of engineering effort over a period of one year.

3.0 TIES AA APPLICATION CONSIDERATIONS

In this chapter we discuss the impact of specific applications such as JTIDS and GPS upon TIES AA architecture.

3.1 TIES AA For Frequency Hopped Signals

TIES is capable of coherently multiplexing up to twenty 10 MHz wide channels onto a broadband FDM cable for delivery to a standard 70MHz IF central processing system. It is also able to geometrically distribute a 10MHz coherent reference on the FDM cable. With the addition of an outboard frequency hopped (FH) synthesizer and a dehopping mixer at the output of each antenna in an array, TIES can be used for AA nulling of jammers of extremely wideband FH receivers. This concept is illustrated in Figure 3-1 using the same 70MHz IF AA beamformer that was described in the first two chapters of this report. JTIDS (Joint Tactical Information Distribution System) uses a very wideband FH waveform at L band and is a candidate for this FH TIES AA concept.

3.2 TIES AA to Provide AJ for GPS Navigation and for JTIDS

The USAF's Space and Missile System Organization (SAMSO) is developing the NAVSTAR Global Positioning System (GPS) to provide military (private, P-code) and civilian (clear access, C/A code) users with a highly accurate, all weather, jam resistant navigation system. Twenty four satellites in 11,000 nautical mile high orbits will broadcast spread spectrum quadrature phase signal and ephemeris data using highly accurate atomic clocks. Users will determine their positions in three dimensions by monitoring four satellites simultaneously (GPS X-Receiver) or sequentially (GPS Y-Receiver) and determine relative distance by measuring PSK code phase. NAVSTAR broadcasts 10.23 Mbps signals in two bands: L1 (1227 MHz) and L2 (1575 MHz), the latter band is for ionospheric delay correction. Navigational accuracy to better than 10 meters permits all weather weapon delivery by aircraft, cruise missiles, etc. It is expected that important enemy targets will be defended by L-band jammers to thwart GPS terminal guidance.

An IF adaptive nulling antenna array integrated into TIES can provide additional AJ to a GPS spread spectrum receiver, thereby enhancing weapon delivery by permitting position location close to an enemy target. The TIES AA system described in section 3.1 can easily be modified to simultaneously protect both GPS and JTIDS (6) receivers. The pulse type JTIDS waveform has unused bursts of time between pulses that could be employed to serve the GPS function. The TIES AA approach for FH waveforms includes an outboard FH synthesizer to generate L0's to frequency convert the FH JTIDS signal down to a common IF for on-bus coupling. Adaptive beam formation with TIES takes place inboard

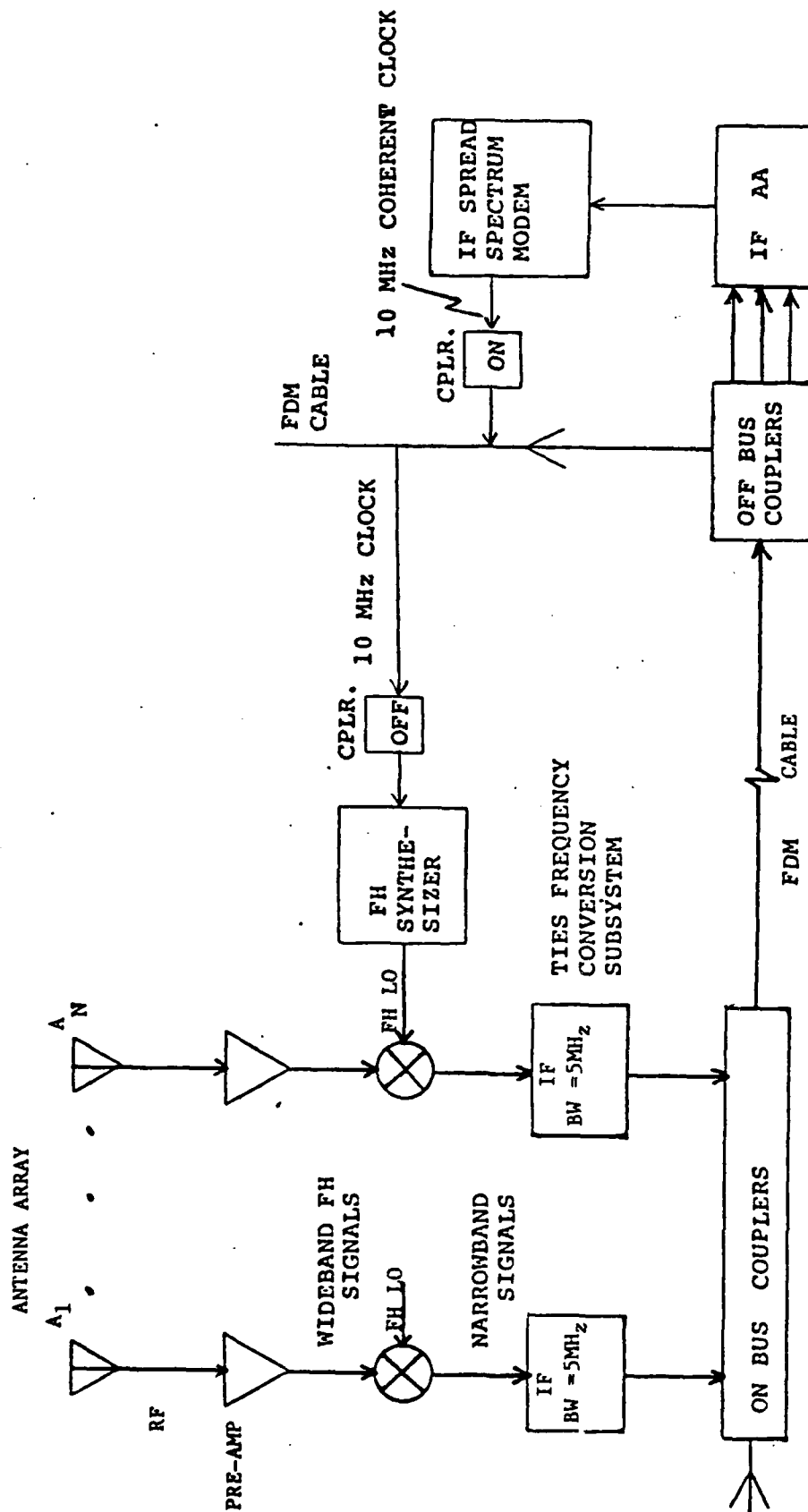


Figure 3-1 TIES - AA FOR WIDEBAND FH SIGNALS

at a standard 70 MHz IF on a pulse by pulse basis for the JTIDS DTDMA format. Each JTIDS 12.8 microsecond "basic event" contains a single 6.4 microsecond pulse, leaving 6.4 microseconds of unused time. To serve GPS the FH synthesizer need only be switched to the RF-IF offset for GPS's L1 or L2. The antennas, the TIES RF front ends, IF's and array beamformer should be able to accommodate the 10.23 megachip/sec. P-code GPS waveform and the 1.023 megachip/sec C/A code.

Navigation information changes slowly for GPS and ephemeris data is at a 100 Hz rate. The sampling theorem can be invoked to demonstrate that the sampling of GPS signals* once every 12.8 microseconds is sufficient for good navigational performance. All GPS satellites broadcast on the same L1 and L2 bands but are distinguished by different spread spectrum codes. The fast AA proposed for TIES can well serve to optimize the signal to jam-plus-noise-ratio for GPS by utilizing modem code information to provide array gain toward the satellite being used on an inter-pulse basis.

To summarize the TIES AA dual JTIDS-GPS AJ operation:

(a) Prior to the arrival of a users signal the FH synthesizer selects the next JTIDS pulse frequency for translation to the array system IF.

(b) The AA rapidly nulls all jammers then present in the next 5 MHz frequency window.

(c) The 6.4 microsecond long JTIDS pulse arrives and is received.

(d) The FH LO switches to receive GPS L1 and then L2 for a few microseconds.

(e) The IF AA nulls jammers in the GPS bands, initially on a power discrimination basis using the apriori knowledge of the expected incident signal strengths (-133 dBm to -127 dBm) from the NAVSTAR satellites.

(f) The GPS modem relocks on the P signals and provides the AA with updated spread spectrum code phase and the AA optimizes $S/(J+N)$ for each satellite.

(g) The FH LO then goes to step (a) above and the process repeats.

Presently GPS receivers use an IF = 184 MHz for code and carrier tracking channels but these could be converted to the TIES 70 MHz standard IF. It is expected that jammers in the GPS bands could be nulled by 30 dB by the TIES AA. This would greatly extend GPS usefulness since GPS carrier track fails when the J/S ratio reaches 43 dB at the receivers input.

*Each received GPS signal has its spread spectrum code removed and is then passed through a filter having a bandwidth of 50Hz. Sampling takes place after this narrow band filter. Phase, frequency and code locked tracking loops have a flywheel effect that permits coherent demodulation of GPS signals even though there are outages when JTIDS pulses are being processed by the AA.

4.0 TIES AA ALTERNATE ARCHITECTURES

The TIES AA is a distributed signal processing system spanning RF, IF and baseband. Here we compare system configuration tradeoffs to determine how much AA hardware should be placed "outboard" at the antennas and how much should be placed "inboard" at the centralized IF processor.

4.1 All Inboard AA Processing

It is useful to refer back to the AA block diagram in Figure 1-1 and the inboard TIES AA concept shown in Figure 1-6.

4.1.1 Advantages of Inboard AA Processing

- (1) For arrays consisting of antennas scattered all over the airframe (eg HF) this system avoids multiple cable runs from antennas to the AA beamformer (BF).
- (2) No changes in the TIES concept is required.
- (3) The AA BF resource is shared among the various frequency bands.
- (4) The time-shared concepts described in sections 2.4 through 2.6 are easily applied at the central processor.

4.1.2 Drawbacks of Inboard AA Processing

- (1) The FDM channels must have matched phase and amplitude frequency characteristics to assure deep nulling. A 1% amplitude variation or .01 radian phase variation between channels will limit the AA null depth to 40 dB at the frequency which the variation takes place⁽²⁾.
- (2) If only one AA BF is provided at the central IF processor then only receivers in one frequency band can be protected from jammers at any one time. Of course additional AA beamformers at IF will permit multiple band ECCM.
- (3) Many FDM channels are consumed with conveying antenna signals to the central processor.

4.2 All Outboard AA Processing

Referring back to Figure 1-5 will help illustrate this concept. Suppose we located a separate AA processor outboard for each frequency band as shown in Figure 1-5 but use the TIES to convey the BF outputs back to central IF versions of the HF, VHF, UHF and Lx-band receivers. Then the TIES is employed as shown in Figure 1-2 but with an AA replacing a single antenna.

4.2.1 Advantages of Outboard AA Processing

- (1) A minimum of TIES FDM channels are consumed.
- (2) ECCM protection is available for each band that has an AA processor.

(3) For a compact array of antennas (eg. $\lambda/2$ interelement spacing at L_x band), short and well matched cable runs from the antennas to the BF will assure deep broad band spatial nulls.

(4) Preamplifiers and frequency converters are already available outboard in the TIES system so achieving a common IF outboard is not difficult. Thus the AA processor could be located outboard and could also be implemented from standard IF components.

4.2.2 Disadvantages of Outboard AA Processing

(1) The AA BF is a multiple input linear system that requires extremely high gain to achieve deep nulls. Locating such hardware outboard will increase implementation costs because of the more severe physical environment.

(2) Maintenance of equipment located at antenna sites is more difficult than equipment located in a central bay.

(3) The outboard AA processors are resources which are dedicated to particular array and serve no useful function when that antenna array is not in use or when it is in use but not being jammed.

(4) Each array processor must duplicate functions performed by every other AA. This redundancy is expensive to acquire and to own and to fly.

4.3 Partially Inboard/Outboard AA Processing

We again refer back to Figure 1-4 to see if there might be an optimal inboard/outboard division of this system. The TIES broadband FDM distribution system will join the bisected parts of the AA. To identify a bisection we need only describe the point in the block diagram of Figure 1-4 at which the FDM cable replaces a direct connection.

4.3.1 Outboard Complex Weighting, Inboard Coherent Summing

This system concept splits the AA beamformer (BF) as shown in Figure 4-1. Instead of placing the antenna signals X_1, \dots, X_N on the TIES FDM cable, the weighted outputs $W_1 X_1, \dots, W_N X_N$ are placed on the cable and brought to the central IF processor where they are coherently summed. The error signal ϵ is filtered and amplified and then shipped sequentially to each antenna site for correlation (multiplication) with each X_N . An FDM sequencer controls the on buss coupler for the error signal to route it to the proper antenna site. The integrator in Figure 1-4 is replaced by an integrate and hold (I&H) circuit in Figure 4-1. The n -th I&H circuit holds its correlation value while the other $N-1$ antennas receive the FDM error signal.

The major advantage of this configuration over all outboard processing is that all the high gain, filtering, desired signal subtraction, and other processing that is required on the error channel is performed at a central IF processor and is available to serve all frequency bands. One drawback is that $N+1$ FDM channels are required for a compact N element array (plus sequenci

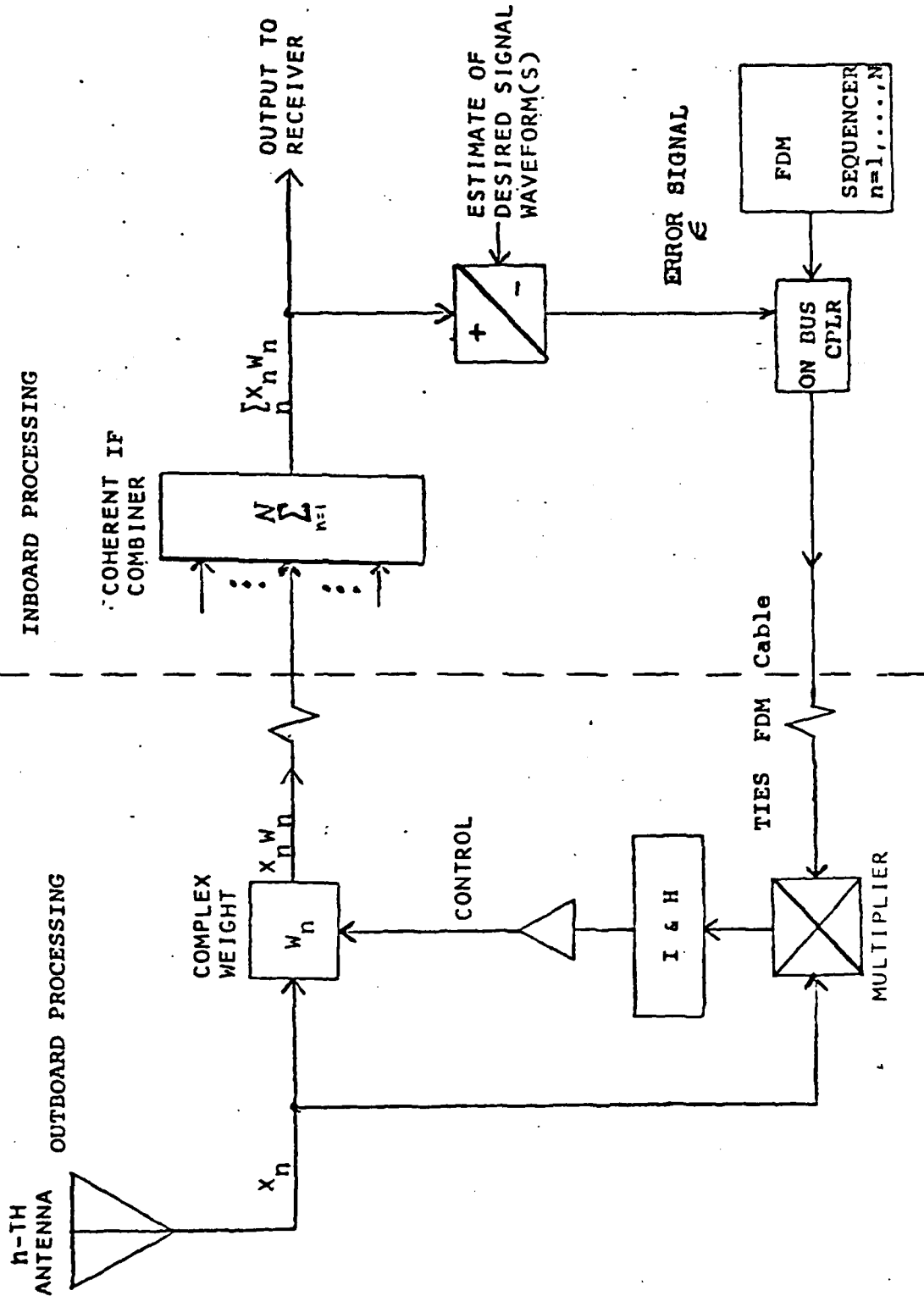


FIGURE 4-1 TIES - AA WITH OUTBOARD COMPLEX WEIGHTING AND INBOARD COHERENT SUMMING

error channel) compared to just one FDM channel required by the all outboard configuration. A second drawback of inboard combining is that the FDM wideband distribution system must bear the full S+J dynamic range. Since jammers are nulled at the output of the BF, the outboard combiner drives the FDM cable with a dynamic range that is reduced by the depth of the AA's null on the largest jammer.

4.3.2 Outboard Beam Formation, Inboard Adaptive Control

This TIES -AA architecture is diagrammed in Figure 4-2. Since its entire BF is located outboard, the AA output signal it places onto the TIES FDM cable has its dynamic range reduced by the null depth on the largest jammer.

An outboard FDM sequence into the on buss coupler routes the antenna signals X_1, \dots, X_N sequentially onto the FDM cable for inboard multiplication with the error signal. The outputs of the multiplier are integrated for a brief period of time to develop the LMS control signal for the n-th complex weight. These control signals are sequentially routed to the outboard weights via the TIES data distribution system (or via the FDM cable). Outboard sample and hold (S&H) circuits store these control signals for the complex weights between updates. The integrator then dumps the n-th control signal and is ready to process the next antennas waveform.

An advantage of this system over the all inboard processing is that it requires only two inbound TIES channels and one outbound channel.

The disadvantage here is the dedication of so much equipment to a single frequency band.

4.3.3 Inboard LMS Error Processing

In this configuration we place most of the AA hardware outboard but locate the LMS error signal processing inboard at IF. With reference to Figure 4-3, we see that only two TIES FDM cable channels are required for an N element array (BF channel and error channel). The advantage over all outboard processing is that the error channel processor can be time-shared among different frequency bands. The advantage of this system over that shown in Figure 4-1 is that fewer TIES channels are needed (two vs. $N+1$).

Comparing Figures 4-2 and 4-3 we see that the system in 4-3 requires one less FDM channel but places more hardware at each antenna site where it can only serve that site.

4.4 Summary

The most attractive configuration appears to be the one where all AA processing is done inboard, i.e. where the output of each antenna is brought to a central IF processor via the TIES wideband signal distribution system. As long as the FDM cable has the capacity to bring these wideband, wide dynamic range signals inboard, its advantages outweigh its drawbacks.

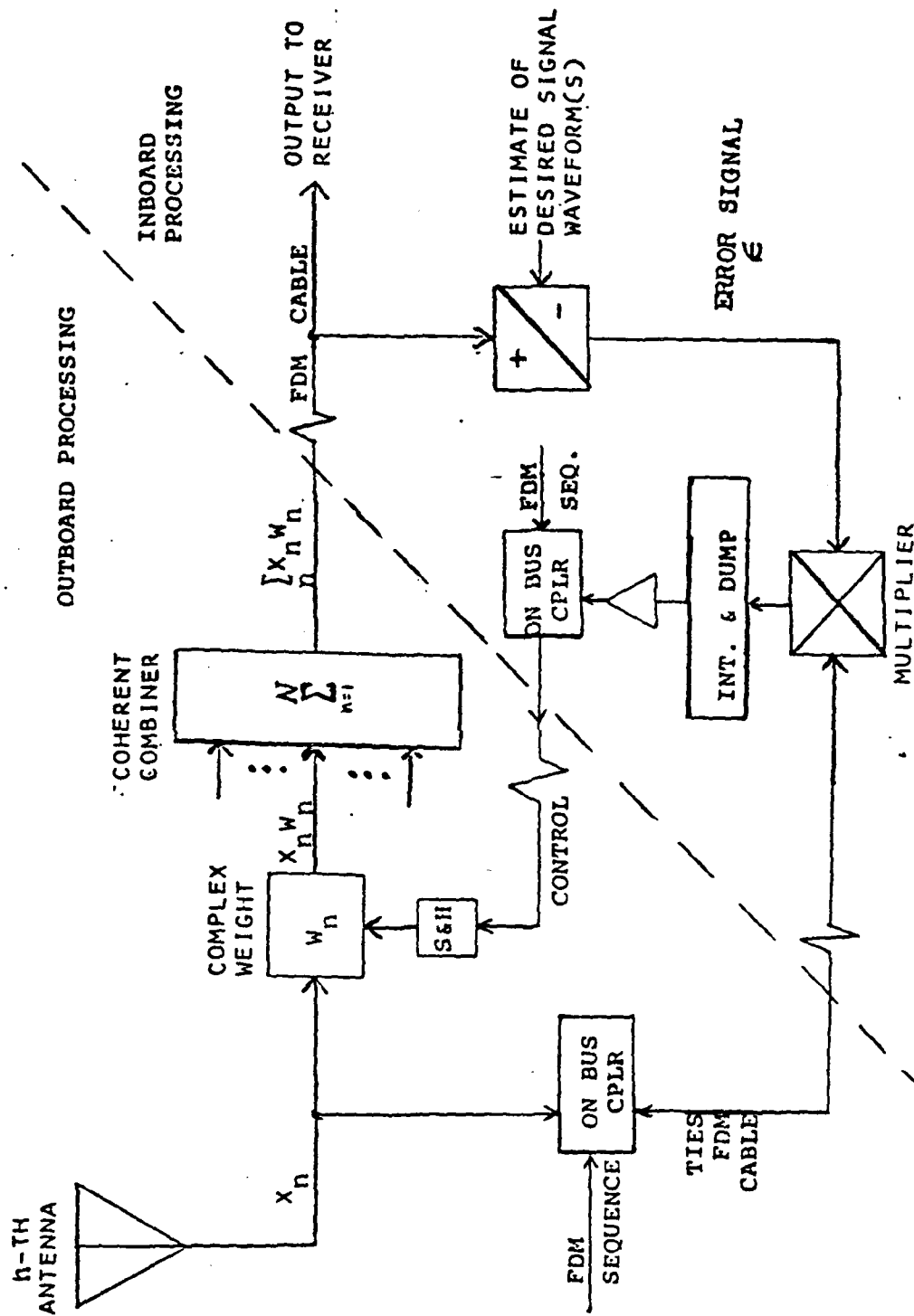


FIGURE 4-2 OUTBOARD BEAMFORMER AND INBOARD AA CONTROL

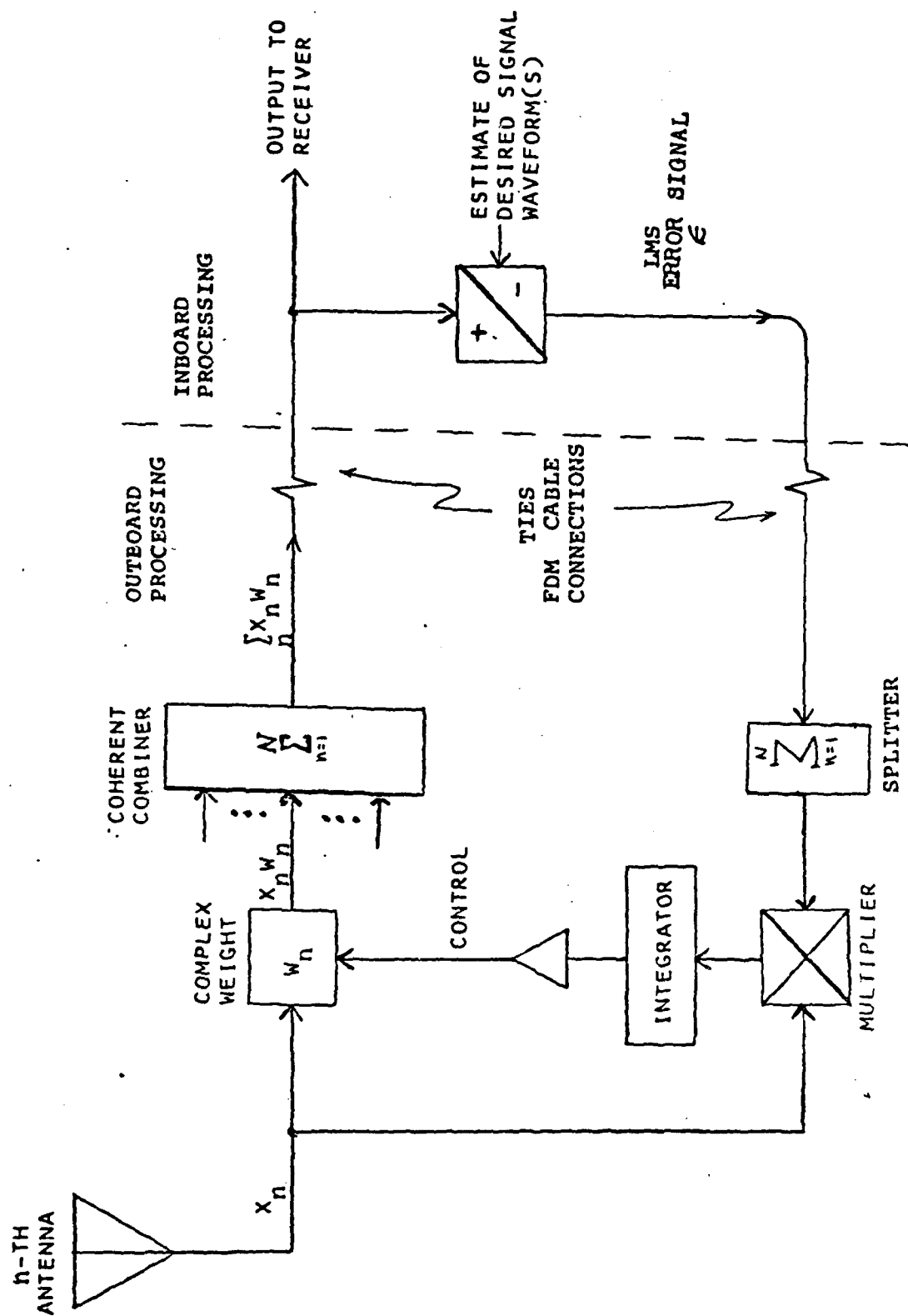


FIGURE 4-3 TIES AA WITH INBOARD LMS ERROR PROCESSING

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20. are presented. Candidate implementation schemes are examined for the TIES-AA.

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